The impact of extreme temperature on human mortality in the most populated cities of Romania

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Corresponding Author:	Adina-Eliza Croitoru, PhD. Babes-Bolyai University Faculty of Geography Cluj-Napoca, Cluj ROMANIA
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Babes-Bolyai University Faculty of Geography
Corresponding Author's Secondary Institution:	
First Author:	Andreea-Sabina Scripcă, PhD. Student
First Author Secondary Information:	
Order of Authors:	Andreea-Sabina Scripcă, PhD. Student
	Adina-Eliza Croitoru, PhD.
	Fiorella Acquaotta, PhD.
	Simona Fratianni, Associate Professor
Order of Authors Secondary Information:	
Funding Information:	Universitatea Babe-Bolyai (0000) — Miss Andreea-Sabina Scripcă Università degli Studi di Torino (00000) — Dr. Simona Fratianni
Abstract:	The impact of extreme weather conditions on humans is one of the most important topic in biometeorology studies. The main objective of this study is to analyze the relationship between temperature-related weather conditions and natural mortality. In the five most populated cities in Romania: Bucharest, Cluj-Napoca, Constana, Iai and Timioara. The results of the study aim to cover a gap in the national research. For the present research we used daily natural mortality data, and daily meteorological data (minimum, mean, and maximum air temperature, wind speed at 10 m above ground, relative humidity, cloudiness). The use of four climate indices (amount of cool days, amount of hot days, amount of cold nights, amount of warm nights) developed by the Expert Team on Sector-Specific Climate Indices, the bioclimatic index Universal Thermal Climate Index, and distributed lag non-linear model has allowed to identify the weather conditions associated with natural mortality. The most important results are: i. higher daily mortality is associated with high frequency of heat stress conditions; ii. higher maximum temperature increases the relative risk of natural mortality; iii. the maximum number of fatalities was recorded on the first day of the hot thermal events. The main conclusion of the study is that inhabitants of the most populated cities of Romania are more sensitive to thermal hot stress compared to the thermal cold stress.
Suggested Reviewers:	Mladjen Curic, PhD. Professor, Belgrade University curic@ff.bg.ac.rs Professor Curic is a well-known professor with numerous previously published research papers in climatology, including human biometeotology.

	Hadas Saaroni, PhD. Associate Professor, Tel Aviv University saaroni@tauex.tau.ac.il; saaroni@post.tau.ac.il Professor Saaroni is a well-known researcher in the field of human biometeorology.
	Francisco de Assis Mendonca, PhD. Professor, Universita Federeale del Parana chico@ufpr.br Prof. Francisco de Assis Mendonca is well-known researcher in the field of human biometeorology.
	Giovenale Moirano, PhD. University of Turin giovenale.moirano@unito.it Dr. Giovenale Moirano works in the field of human biometeorology.
	Daniel Joly, PhD. Professor, Universite de Franche-Comte daniel.joly@univ-fcomte.fr Prof. Joly is a specialist in the field of climatology-bioclimatology.
	Mariam Elizbarashvili, PhD. Professor, Ivane Javakhishvili Tbilisi State University mariam.elizbarashvili@tsu.ge Prof. Elizbarashvili is a specialist in working with extreme temperature indices and their impact on society and environment.

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Title: **The impact of extreme temperature on human mortality in the most populated cities of Romania**

Author names and affiliations:

Andreea-Sabina Scripcă[a], Fiorella Acquaott [b,c], Adina-Eliza Croitoru[d], Simona Fratianni [b,c]

Andreea-Sabina Scripcă /Andreea-Sabina (given name) Scripcă (family name)[a]

[a] Babeş-Bolyai University, Doctoral School of Geography, 5-7, Clinicilor Street, 400006, Cluj-Napoca, Romania. scan13022@studmail.ubbcluj.ro; sabina_scripca@yahoo.com. ORCID ID - 0000-0001-9736-2304

Fiorella Acquaotta /Fiorella (given name) Acquaotta (family name)[b, c]

[b] University of Turin, Department of Earth Sciences, Via Valperga Caluso 35, 10125 Turin, Italy

[c] Centro Interdipartimentale sui Rischi Naturali in Ambiente Montano e Collinare, NatRisk University of Turin, Turin, Italy. fiorella.acquaotta@unito.it . ORCID ID - 0000-0002-9498-3313

Adina-Eliza Croitoru/Adina-Eliza (given name) Croitoru (family name)[d]

[d] Babeş-Bolyai University, Department of Physical and Technical Geography, 5-7, Clinicilor Street, 400006, Cluj-Napoca, Romania. adina.croitoru@ubbcluj.ro; adina04@yahoo.com. ORCID ID - 0000-0003-1235-4327

Simona Fratianni/Simona (given name) Fratianni (family name)[b, c]

[b] University of Turin, Department of Earth Sciences, Via Valperga Caluso 35, 10125 Turin, Italy

[c] Centro Interdipartimentale sui Rischi Naturali in Ambiente Montano e Collinare, NatRisk University of Turin, Turin, Italy. simona.fratianni@unito.it. ORCID ID - 0000-0002-8706-882X

Corresponding author:

Adina-Eliza Croitoru,

Babeş-Bolyai University, Department of Physical and Technical Geography, 5-7, Clinicilor Street, 400006, Cluj-Napoca, Romania. Mobile: + 40 744 496552. E-mails: adina.croitoru@ubbcluj.ro; adina04@yahoo.com

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The impact of extreme temperature on human mortality in the most populated cities of Romania

Andreea-Sabina Scripcă, Fiorella Acquaotta, Adina-Eliza Croitoru, Simona Fratianni

Abstract

The impact of extreme weather conditions on humans is one of the most important topic in biometeorology studies. The main objective of this study is to analyze the relationship between temperature-related weather conditions and natural mortality. In the five most populated cities in Romania: Bucharest, Cluj-Napoca, Constanța, Iași and Timișoara. The results of the study aim to cover a gap in the national research. For the present research we used daily natural mortality data, and daily meteorological data (minimum, mean, and maximum air temperature, wind speed at 10 m above ground, relative humidity, cloudiness). The use of four climate indices (amount of cool days, amount of hot days, amount of cold nights, amount of warm nights) developed by the Expert Team on Sector-Specific Climate Indices, the bioclimatic index Universal Thermal Climate Index, and distributed lag non-linear model has allowed to identify the weather conditions associated with natural mortality. The most important results are: i. higher daily mortality is associated with high frequency of heat stress conditions; ii. higher maximum temperature increases the relative risk of natural mortality; iii. the maximum number of fatalities was recorded on the first day of the hot thermal events. The main conclusion of the study is that inhabitants of the most populated cities of Romania are more sensitive to thermal hot stress compared to the thermal cold stress.

Keywords: Bioclimatic stress; Extreme temperature; Bioclimatic indices; Natural mortality; Romania

1. Introduction

In the last century, climate change has been considered one of the biggest threats to human health (IPCC 2015; Vicedo-Cabrera et al. 2019). Due to intensification of climate change by increasing the frequency and intensity of extreme weather-related events, researchers worldwide have focused their attention on studying the impact of meteorological variables and/or different weather-conditions on humans (e.g. Morabito et al. 2014; Acquaotta et al. 2017; Di Napoli et al. 2018; Moirano et al. 2018; Chai et al. 2019; Croitoru et al. 2019; Sangkharat et al. 2020).

Many of the latest research analyzed the relationship between air temperature, including extreme temperature conditions, and mortality (De' Donato et al. 2015; Gasparrini et al. 2015; Guo et al. 2017; Åström et al. 2018; Scovronick et al. 2018; Smith and Sheridan 2019; Royé et al. 2020). Some studies investigated the impact of air temperature considering general mortality (natural causes of death), some other focused on different groups of deseases (respiratory or cardio-vascular deseases) (e.g. Gasparrini et al. 2015; Chen et al. 2018; Scortichini et al. 2018).

The impact of weather and climate on humans' health can be assessed by using the climatic and bioclimatic indices (Nastos and Matzarakis 2011; Vaneckova et al. 2011; Di Napoli et al. 2018). Among them, the Universal Thermal Climate Index (UTCI) synthesizes very well the heat stress induced by meteorological conditions to the human body (Błażejczyk et al. 2018; Di Napoli et al. 2018).

Other researchers identified the high impact of heat on humans in several major cities in Europe. In detail, excessive heat in Europe (identified by heat waves) has led to a greater impact in the Mediterranean region than in the northern continental cities (Baccini et al. 2008; D'Ippoliti et al. 2010). The low and the high temperatures increase the risk of producing deaths under different climatic conditions: population living in colder climate areas, is more sensitive to the high temperatures, and the inhabitants of the warmer climate areas are more vulnerable to low temperatures (Kovats and Hajat, 2008; Zhang et al., 2014). Population seems to be less able to cope with the extreme heat, compared to the extreme cold (Barnett et al., 2012). As a possible explanation for adapting to environmental conditions is the behavior of the inhabitants of certain parts of Europe. People in the cold regions of Europe take more cold-protective measures compared to the inhabitants of the warm regions (Keatinge et al., 2000).

There are only a few studies focused on Eastern European countries (e.g. Pattenden et al. 2003; McMichael et. al. 2008; Papathoma-Koehle et al. 2016). Concerning Romanian state, the researchers on climate and health is still scarce. Only a small number of studies focused on Romania's territory so far, and most of them are part of researches investigating larger regions. In general, they considered single cities like Bucharest (McMichael et. al. 2008), Cluj-Napoca (Croitoru et al. 2018), or other areas (Leitte et al. 2009; Papathoma-Koehle et al. 2016), but none of the previous papers have been conducted to cover more cities in this country.

The main objective of this study is to analyze the relationship between severe thermal conditions, assessed by using simple or complex bioclimatic indices, and natural mortality recorded in the five most populated cities in Romania. We intend to carry out the risk assessment for human health under certain climatic conditions.

2. Materials and methods

2.1. Reference population and environment

Romania is located in Eastern Europe, in a temperate climate in transition from western maritime climate to semi-arid continental climate. There are some regional differences, induced by the presence of the Carpathian Mountains, which form a natural barrier in front of different types of air masses. As general features, the Extra-Carpathian regions (eastern and southern Romania) are hotter in summer, colder in winter and drier all over the year compared to the Intra-Carpathian regions, which are wetter and cooler during summer and milder in winter (Sandu et al. 2008; Piticar et al. 2017). The Black Sea serves as an important climate moderator for the south-eastern region of the country.

For this study, we considered 5 cities: Bucharest (1), Cluj-Napoca (2), Constanța (3), Iași (4) and Timișoara (5). They are located in various local conditions in terms of topography and climatic conditions covering very good almost all regions of Romania. Their spatial distribution is presented in *Fig 1*.

Fig. 1. Study area and considered weather stations.

The most relevant climatic features of the cities studied are detailed in *Supplementary material 1.*

Their climatic specificity derives from their position and from air mass tracks over the region: Atlantic oceanic influence is dominant in Cluj-Napoca; Timișoara is more influenced by the Mediterranean and the Atlantic Ocean; the semi-arid East-European climatic influence is dominant in Bucharest and Iași, whereas Constanța, located on the Black Sea shore has a more humid and temperate moderate climate (Badea et al. 1983; Sandu et al. 2008).

All these urban entities are among the most economically developed cities in the country, with prestigious universities and an important medical infrastructure, including a network of renowned university hospitals.

The cities included in this study are the top five most populated cities in the country, considering the number of inhabitants residing in Romania, on July 1, 2016 (http://www.insse.ro). In 2016, the population of the capital city, Bucharest, exceed two million inhabitants (2,102,675 inhabitants) and the other four cities had a population between

316,000 and 366,000 inhabitants each (321,965 in Cluj-Napoca; 316,777 in Constanța; 365,660 in Iași; and 332,192 in Timişoara) (http://www.insse.ro).

2.2. Data collection

To develop the present study we used historical daily weather data as well as daily mortality data over a 18-yr period (1999-2016) registered in the five cities mentioned above. The period was selected according to the mortality data availability (death with the clear diagnosis mentioned) and it is long enougth not to be influenced by inter-annual variations and anomalies (Storch and Zwiers 2003; Acquaotta et al. 2017, 2019).

2.2.1. Mortality data

The mortality data were freely provided by the National Institute for Statistics (NIS) as anonymized (unidentifiable) mortality microdata (individual data).

For the period 1999-2016, the datasets include the dead people with the stable (permanent) residence or normal residence (defined as the place/city where a person lived mostly in the last 12 month of his/her life) in the five cities considered. Also, the database includes leading cause of death classified by the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10) (WHO 2016).

In this study we used only the data on natural mortality (deaths with disease codes between A00-R99).

2.2.2. Meteorological data

For this analysis, historical daily maximum (TX) and minimum (TN) temperature data over the period 1999-2016 were used. They were collected from different sources: for the period 1999-2009, the data were freely downloaded from ECA&D project database (Klein Tank et al. 2002; www.ecad.eu) (non-blend data series) and for the period 2010-2016, they were reconstructed from row synoptic messages available on www.meteomanz.com. The datasets corresponding to the Timișoara weather station were collected from the ROCADA database (for the period 1999-2013) (Dumitrescu and Bîrsan 2015) and supplemented with data extracted from www.meteomanz.com for the period 2013-2016. Partially, these data sets were developed under the framework of the project *Extreme Weather Events related to Air Temperature and Precipitation in Romania* (www.granturi.ubbcluj.ro/fmetpro).

Mean daily values of temperature (T), relative humidity (RH), cloudiness (N), wind speed at 10 m height (v10), were provided by the Romanian National Meteorological Administration (RNMA). In case of missing data, they were derived as follows:

• for the Bucharest-Băneasa weather station, the N missing data from 2001 were filled in with the data from the archive available on www.meteomanz.com;

• for Cluj-Napoca weather station, the T data were extracted from the ECA&D project archive (Klein Tank et al. 2002; https://www.ecad.eu/) (for the interval 1999-2015) and from www.meteomanz.com (for the year 2016);

• also, for Cluj-Napoca weather station data for the year 2016, the v10, RH and N were downloaded from www.meteomanz.com and www.rp5.ru.

2.3. Methods

2.3.1. Data quality control

Data quality control (QC) represent a pre-requisit step; both meteorological and mortality data were checked for quality and homegeneity before using them in analysis.

The QC of the temperature datasets was performed by employing ClimPACT2 software, which allowed us to identify outliers and other unrealistic values (Baronetti et al. 2018). Temperature series were tested for homogeneity by employing RhtestV4 (Wang and Feng 2013; Fortin et al. 2016).

The RH, N, and v10 data series were provided by the Romanian National Meteorological Administration (RNMA) as homogenized datasets.

For the analyzed period, the missing data were only for the Constanța station, for the meteorological parameters v10m and RH (with values of 0.5%, respectively 0.2%).

Mortality data were checked for each city. Some data have been invalidated because the disease code was not clearly specified, and thus they have been excluded from further analysis. They covered an insignificant number of deaths: 0.001% in Bucharest; 0.002% in Constanța and Iași.

2.3.2. Indices calculation

The analysis was carried out on four climate extreme indices: amount of cool days (TX10p), amount of hot days (TX90p), amount of cold nights (TN10p), amount of warm nights (TN90p) (*Table 1, section a)).* They are part of the core indices list created by the Expert Team on Sector-specific Climate Indices (ET-SCI) (Alexander and Herold 2016). The fifth index is a complex bioclimatic index: Universal Thermal Confort Index (UTCI). It is one of the most recent thermal climate indeces developed by a multidisciplinary research team, in the frame of COST Action 730 (Bröde et al. 2012; Jendritzky et al., 2012).

We have also calculated the daily values of UTCI. To derive the data sets, the BioKlima ver. 2.6 freely available software package was used (https://www.igipz.pan.pl/Bioklima-zgik.html).

In this study, the UTCI values are calculated as a polynomial regression function and the input data include meteorological (T, mean radiant temperature, RH, and v10, and non-meteorological (a metabolic rate of 135 W m^{-2} and a walking speed of 1.1 m s^{-1}, albedo of clothing) data (Blazejczyk et al. 2012, 2015). Radiant temperature is necessary for UTCI calculations. Therefore, the statistical SolAlt model (Błażejczyk and Matzarakis 2007; Blazejczyk et al. 2015, 2018) was adopted in order to use as input data for total cloud cover, sun altitude and albedo of clothing (Blazejczyk et al. 2015). The stress categories for UTCI index are presented in *Table 1, section b).*

Table 1. a) Definitions of the ET-SCI climate indices analysed (after Alexander and Herold 2016); b) Assessment scale for the UTCI index (after Glossary of Terms for Thermal Physiology (2003); www.utci.org; Błażejczyk et al. 2012 (modified)).

2.3.3. Relationships between indices and natural mortality

a. Relationship beetween ET-SCI temperature-based indices and natural mortality

The first relationship between climate index and mortality was carried out using the anomaly index. The anomaly indice was calculated taking into account the annual average (per year for the period analyzed) (AnnMM), and multi-annual average (during 1999-2016) for number of deaths (MannMM). We identified the years when the mortality was above the mean multi- annual average (naming those years as having in excess mortality), and years with the mean annual number of deaths was below the multiannual value (years with deficit mortality). Then we analyzed the indicators values during the years with excess and deficit of mortality.

b. Relationship beetween UTCI and natural mortality

To correlate the mortality values with daily UTCI, we employed daily mortality data and the analysis was performed at a seasonal scale and for the extreme seasons: summer (June-July-August) and winter season (December-January-February). The reason for this selection was that climatic characteristics are very different in these two seasons, and we wanted to find out when exactly the human body is the most vulnerable. On the other hand, we chose to conduct this analysis at the season scale, because the number of deaths is different (the highest in the winter and the lowest in the summer). The same seasonal distribution of deaths was reported in other studies, too (Rodrigues et al., 2019).

Also, for this analysis we used the anomaly index. Initially, we calculated the daily mean multi-annual value of mortality for each season chosen for this analysis. Then, we selected those days when deaths number was at least equal to or higher than the mean daily mortality. In the next step we calculated the frequency of days with mortality greater than or equal to the average value (*excess mortality days*) (*Ex.M*) and the frequency of days when the number of deaths was below average (*deficit mortality days*) (*De.M*) for each class of bioclimatic comfort.

2.3.4. Calculation of relative risk for mortality in case of extreme temperature

The distributed lag non-linear model (DLNM) was used to examine the relationship between daily TX and TN and daily natural mortality during the mentioned interval, with a maximum lag of 20 days. Since, numerous previous studies revealed that the cold effect is spread over a week or more after a cold day and the heat effect is more immediate (Armstrong 2006), we decided to extend the lag period to 20 days to include the long delay of the effects of cold and hot temperature and for potential short-term mortality displacement.

DLNM allows describing the exposure-lag-response association, considering the non-linear temperature-mortality relationship and its delayed effects over time (Gasparrini 2011). The cross-basis for temperature is composed by double-threshold functions with cut off points at 25^{th} / 20^{th} percentile and 75^{th} / 80^{th} percentile for the dimension of the predictor and a natural cubic spline with knots at equally spaced values in the log scale for lag. The cross-basis matrix is included in the the package dlnm (Gasparrini 2011).

All tests listed above were performed for individual cities, for the period 1999-2016.

2.3.5. Visualization

The map was drawn using ArcMap10.2 software and the graphs were designed by employing Excel and RStudio packages.

3. Results

3.1. Relationship beetween ET-SCI temperature-based indices and natural mortality

The analysis between climatic indices and natural mortality (Fig. 2) revealed a more pronounced anomaly with hot extremes indices calculated (TX90p and TN90p), emphasizing that urban population is more vulnerable to hot extremes compared to the cold ones. The years when the annual mortality exceeded the mean multi-annual mortality (excess mortality years) were mainly characterized by high values (above the average) of TX90p for Bucharest, Cluj-Napoca, Constanța, and Iași, as well as for TN90p for all cities. We also considered for analysis the consecutive in excess mortality years (2012-2016 for Cluj-Napoca and Iași, 2013-2016 for Timișoara, and 2014-2016 for Bucharest and Constanța), but this analysis did not identify a specific pattern between mortality and indices. Like most European cities, the urban population in Romania faces the phenomenon of demographic aging. This is a possible explanation for the increase in mortality over the average, in the last years analyzed.

Fig. 2 Results of correlations between climate indices and natural mortality, where: AnnMM = annual mean of mortality; MannMM = multiannual mean of mortality

3.2. Relationship beetween UTCI and natural mortality

Daily mortality higher than the mean summer mortality is associated with high frequency of heat stress conditions. 100 % excedence of mean daily mortality (for Bucharest) and 50 % (for Constanța) were recorded during periods of strong heat stress (label 3). Days with excess mortality, with a rate of more than 60 % were found when the UTCI indicates strong heat stress (label 2) (61,5 % - Constanța, 68,6 % - Timișoara, 70,9 % - Iași, 73,8 % - Cluj-Napoca, and 79,6 % - Bucharest). When UTCI identifies thermal comfort conditions (label 0), the mortality has similar rates as during the days in which less deaths than seasonal average is recorded, for four of the five cities examined (except Bucharest) (Table 2). This means that an increasing sensitivity of the population in the focus areas was recorded during hot heat stress conditions.

During winter, most of the days with maximum cold stress conditions registered an excess mortality, too. The days belonging to the extremely cold stress class (label -5) coincide with the days with above average mortality 50 % in Constanța, and 100 % for the cities of Bucharest, Iași and Timișoara. For all cities, during the bioclimatic conditions related to the severe cold stress class (label -3), excess mortality was recorded in more than 50 % of the days, with values ranging from 51,5 % in Cluj-Napoca and 71,4 % in Timișoara. Mortality above average covers less than 50 % of the days included in other classes for cold stress such as moderate cold stress (label -2) and mild cold stress (label -1) for Bucharest and Timisoara and slightly above 50 % for the other three cities analyzed.

Table 2. Correlation between UTCI and natural mortality (%).

The increased risk of death is recorded when bioclimatic stress synthesizes positive thermal conditions; as expected, for cold stress classes, mortality increased during very severe conditions. However, population in the focus cities seems to be more adapted to the bioclimatic conditions given by the cold thermal stress.

3.3. Relative risk for mortality calculated for extreme temperature

The effect of TX and TN on mortality was expressed as the Relative Risks (RR).

The following analysis presents the RR of natural mortality for TX and TN, insisting on the effect in time given by extreme temperatures on human body (*Fig. 3*).

In all cities analyzed (Bucharest, Cluj-Napoca, Constanța, Iași, and Timișoara), the RR of natural mortality was greater in the case of high TX and, in general, for lags of 0 - 5 days (*Fig. 3 a., b., c., d., e.*). The effect of hot thermal extremes is felt in the very first days of the extreme temperature event. Detailing this issue, it turned out that for the mortality in Bucharest, the RR has high values in the first 5 days (0-5 lag), for the deaths recorded in the cities of Cluj-Napoca and Timișoara, the TX effect is present for 7 days from the beginning of the event (RR with high values in the range 0-6 lag). The results for Constanța and Iași revealed the TX effect on mortality increases in the first five consecutive days of the extreme temperature event.

In Bucharest, Cluj-Napoca, Constanța, and Timișoara the TX effect on mortality is maximum on the same day with the temperature increase (lag 0) when the RR recorded its highest values. Thus, the maximum number of casualties occurs immediately after the maximum temperature, and their number decreases gradually afterwards, with the decrease of the RR value. An exception is the city of Iași, where the TX effect on mortality is maximum the day after the highest temperature is recorded (lag 1).

For all the urban areas considered, the TN effect (*Fig. 3- f., g., h., i., j.*) lasts for a much longer period and varies largely from one city to another: from a few days, in Cluj-Napoca and Iași, to about two weeks for the other three cities. These different patterns from one city to another may be also caused by different climatic characteristics of these urban areas. Population living in cities with a more frequent occurrence of positive thermal extremes (Bucharest, Constanța, and Timișoara) is more exposed to longer time effects of cold extremes.

Fig. 3. The RR of natural mortality by maximum temperatures (a., b., c., d., e.) - the *column on the right* indicates the RR value. The RR of natural mortality by minimum temperatures (f., g., h., i., j.) - the *column on the left* indicates the risk of natural mortality.

4. Discussions

Many studies in the literature have focused on the impact of extreme phenomena (such as heat and cold waves) on mortality (e.g. Baccini et al. 2008; D'Ippoliti et al. 2010; Barnett et al. 2012), but there are a few studies that have quantified the results between indices that synthesize thermal extremes and deaths (Yang et al. 2019). We consider that our study fills in such a gap for the five most populated cities in Romania.

In relation to the most complex bioclimatic index, the results from several European countries, have led to the conclusion that the mortality relation - UTCI is strictly related to the thermal bioclimate to which a population is exposed and adapted (Błażejczyk et al. 2018; Di Napoli et al. 2018). The results we obtained are similar to those calculated for Poland (Błażejczyk et al. 2013). In another recent study (Błażejczyk et al. 2018) in comparison to no thermal stress conditions, the significant increase of mortality is observed in days with strong and very strong heat stress conditions.

Our results obtained based on UTCI show that although mortality increases both in hot and cold thermal stress conditions, the stronger effect was recorded during hot thermal stress. They are in line with findings obtained in different regions of the world and makes from this index (UTCI) an important tool to forecast health problems when recording extreme high temperatures (Pappenberger et al. 2015; Di Napoli et al. 2018).

In Romania, a recent study indicated a statistically significant increase in number, duration and intensity of the extreme hot thermal events (heat waves) over the last decades, especially during summer (Croitoru et al. 2018). Another study revealed that climatic changes of extreme thermal events identified based on excess heat factor are more consistent compared to those identified based on excess cold factor (Piticar et al. 2017). Under these circumstances when more frequent, longer duration and higher intensity extreme hot events characterize almost the entire country, including the five cities considered for this research, it is supposed that they severely impact on human health leading to an increase in vulnerability of the population, caused primarily by the nonadaptation to the hot thermal stress. As previosuly presented, the vulnerability can be attributed to poor living conditions, such as small hauses or lacking of air conditioned devices, too (García-Herrera et al. 2010). In Romania, most of the houses in the focus areas (especially the apartments built between 1950 and 1985) are quite small, with two or three rooms in their great majority. The extreme thermal events and heat waves that occur frequently in Bucharest trigger significant thermal stress and thermal risks, especially in buildings with inadequate ventilation (Constantinescu et al. 2016).

It is possible underline that when low temperatures are recorded, individuals are much easier to adapt to these conditions (by wearing warmer clothing, or stay in house as much as possible). By contrast, in order to diminish the impact of extreme heat, people need modern techniques, such as air conditioned, which are relatively new and expensive.

For their operation and maintenance significant amounts of money are needed, which cannot be supported by a great part of Romania's population. Exposure to environmental stressors generates effects delayed in time (Anderson and Bell 2009; Gasparrini et al. 2011). Our results are in agreement with the international researches stating that the positive thermal extremes are felt by the human body on the day the temperature was recorded, respectively the day after. The effects of cold thermal extremes are registered by the human body with a delay of several days and the impact on mortality is exerted over a longer period of time (Anderson and Bell 2009; Gasparrini 2011). We identified for all cities analyzed that the RR values increased with the increase of the TX. Other studies reported that mortality risk increased with temperature or heat waves intensity or duration or (Anderson and Bell 2009; De' Donato et al. 2015; Scovronick et al. 2018).

5. Conclusions

According to analyzes performed, the population of the analyzed cities is sensitive to the thermal conditions that synthesize the most severe cold stress and the vulnerability increases during the bioclimatic conditions of hot thermal stress. The highest risk is specific during hot thermal discomfort periods, or when the maximum temperature exceeds certain thresholds.

Due to the intensification of the extreme temperature events in Romania and high vulnerabilty, measures to prevent and raise awareness of the population, especially when the discomfort of hot thermal stress is predicted are needed. As an immediate consequence, our results can be used to improve the preparation of the public health system for the primary and secondary prevention of the population during periods with adverse weather conditions. These results can become the start point to develop biometeorological forecast system for the Romanian cities and also an early warning system during extreme temperature events.

Furthemore, these findings fill in a gap in the national research and it could be if interest for the valuable increase in the knowledge of the temperature-mortality relationships in a country that is under-studied in the literature.

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Declarations

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Conflicts of interest/Competing interests: The authors declare no conflict of interest. This paper reports independent results and research. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material (data transparency): The authors do not have the permission to publish the mortality microdata or the raw climatic data.

Code availability (software application or custom code): Not applicable.

Authors' contributions: conceptualization: A.S.S; data processing: A.S.S and F.A.; analysis and writing the paper: A.S.S., A.E.C., F.A., S.F.; visualization: A.S.S.; supervision: S.F.; correspondence: A.E.C.

Ethical standards

The research presented complies with the current laws in Romania and with the ethical standards in Babeș-Bolyai University.

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Table 1

Table 1. a) Definitions of the ET-SCI climate indices analysed (after Alexander and Herold 2016); b) Assessment scale for the UTCI index (after Glossary of Terms for Thermal Physiology (2003); www.utci.org; Błażejczyk et al. 2012 (modified)).

a) Simple indexes

Name and abrevations	**Definition**	**Plain language description**	**Units**	**Time scale**
Amount of cool days (TX10p)	Percentage of days when TX < 10th percentile	Fraction of days with cool day time temperatures	%	Year
Amount of hot days (TX90p)	Percentage of days when TX > 90th percentile	Fraction of days with hot day time temperatures		
Amount of cold nights (TN10p)	Percentage of days when TN < 10th percentile	Fraction of days with cold night time temperatures		
Amount of warm nights (TN90p)	Percentage of days when TN > 90th percentile	Fraction of days with warm night time temperatures		

b) Complex index

Stress Category	**UTCI (°C) range**	**Labels**
Extreme cold stress	< -40.1	-5
Very strong cold stress	-4.0 - -27.1	-4
Strong cold stress	-27.0 - -13.1	-3
Moderate cold stress	-13.0 - 0.0	-2
Slight cold stress	0.1 - +9.0	-1
No thermal stress	+9.1 - +26.0	0
Moderate heat stress	+26.1 - +32.0	1
Strong heat stress	+32.1 - +38.0	2
Very strong heat stress	+38.1 - +46.0	3
Extreme heat stress *	> +46.1	4

Table 2

Table 2. Correlation between UTCI and natural mortality (%).

Season	UTCI confort classes	Bucharest		Cluj-Napoca		Constanța		Iași		Timișoara	
		Ex.M	De.M	Ex.M	De.M	Ex.M	De.M	Ex.M	De.M	Ex.M	De.M
Summer	-5	/	/	/	/	/	/	/	/	/	/
	-4	/	/	/	/	/	/	/	/	/	/
	-3	/	/	/	/	/	/	/	/	/	/
	-2	/	/	0.0	100.0	0.0	100.0	100.0	0.0	/	/
	-1	100.0	0.0	75.0	25.0	25.0	75.0	27.3	72.7	66.7	33.3
	0	30.9	69.1	50.5	49.5	46.8	53.2	55.2	44.8	50.0	50.0
	1	46.5	53.5	54.7	45.3	47.9	52.1	59.8	40.2	60.8	39.2
	2	79.6	20.4	73.8	26.2	61.5	38.5	70.9	29.1	68.6	31.4
	3	100.0	0.0	/	/	50.0	50.0	/	/	/	/
Winter	-5	/	/	/	/	50.0	50.0	100.0	0.0	100.0	0.0
	-4	44.4	55.6	/	/	55.8	44.2	53.1	46.9	100.0	0.0
	-3	55.6	44.4	51.5	48.5	63.9	36.1	61.6	38.4	71.4	28.6
	-2	49.1	50.9	51.5	49.1	57.4	42.6	57.9	42.1	45.7	54.3
	-1	47.1	52.9	54.0	46.0	53.7	46.3	59.4	40.6	46.3	53.7
	0	39.4	60.6	61.5	38.5	51.3	48.7	57.1	42.9	50.0	50.0
	1	/	/	/	/	/	/	/	/	/	/
	2	/	/	/	/	/	/	/	/	/	/
	3	/	/	/	/	/	/	/	/	/	/

Note: Ex.M = *excess mortality*; De.M = *deficit of mortality*; / = no days with these bioclimatic conditions recorded.

Figure 1

Click here to access/download;Figure;Fig.1.tif

Figure 2

Click here to access/download;Figure;Fig.2.tif

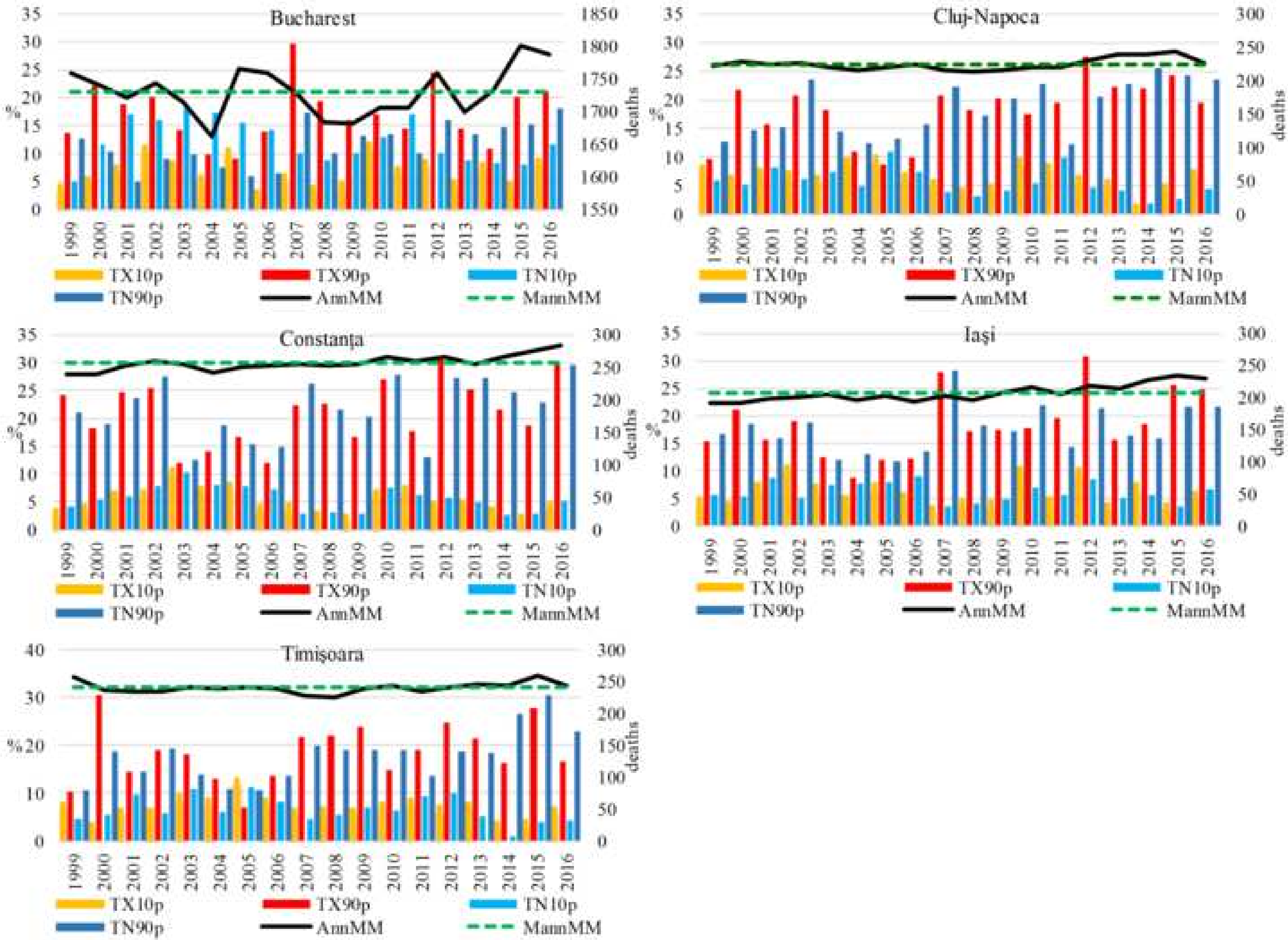
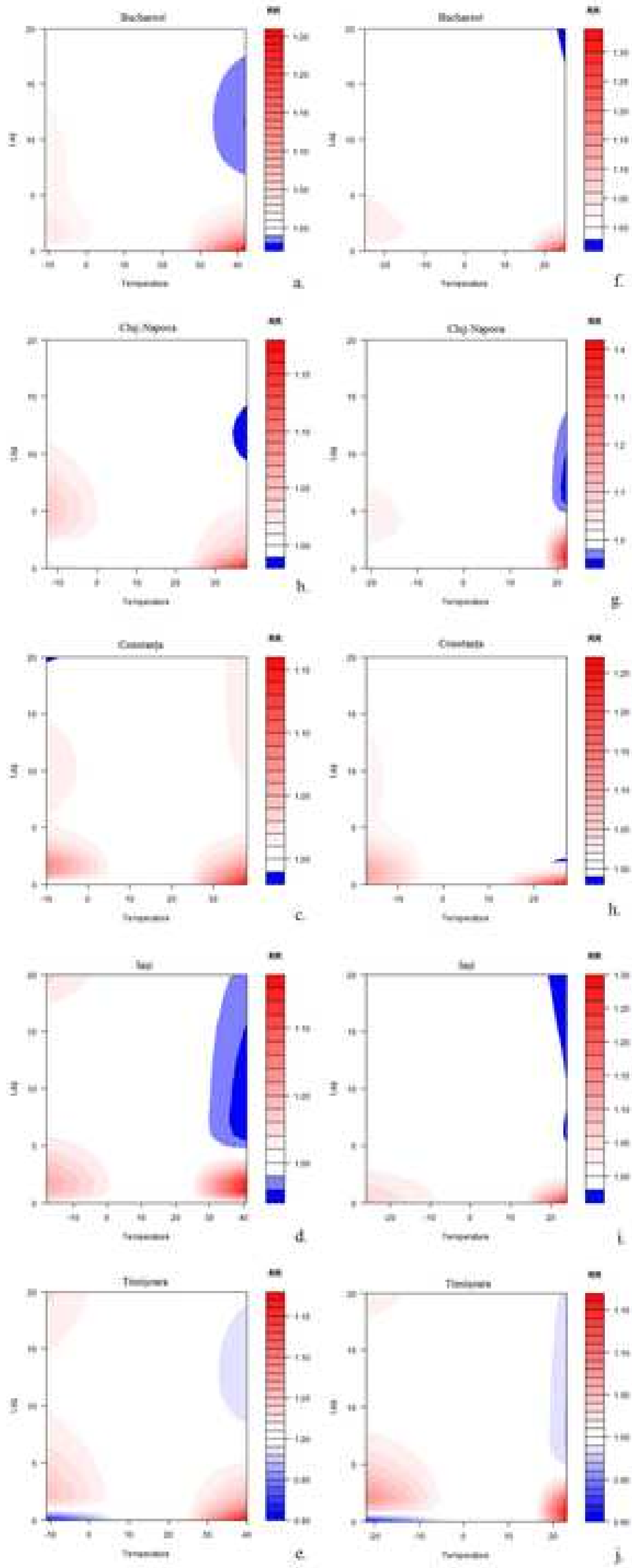


Figure 3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Constanta
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Iasi
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